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THE INFORMATION OF SOUNDS AND PHONETIC DIGRAMS OF ONE- AND TWO-SYLLABLE WORDS

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RESEARCH REPORT

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NAVAL AIR STATION
PENSACOLA, FLORIDA

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15 May 1954

SUMMARY

Approximately 3500 common one- and two-syllable words were transcribed phonetically. The sequences of speech sounds were analyzed in terms of (a) the probability of each sound, (b) the conditional probability of each pair of sounds, and (c) the joint probability of each digram. The maximum information (H) per symbol in an alphabet of 41 symbols (the number treated) would be 5.35 bits (F_0). In the sample studied, the obtained values were 4.15-5.04 bits (F_1) and 3.35-4.21 bits per symbol (F_2). Some transitional probabilities reached 0.33. Among words of a particular length in syllables, the words of few sounds contained the highest information value per symbol.

Digrams of greatest conditional and joint probabilities are enumerated in tables.

INTRODUCTION

Knowledge of the statistics of the English language is limited and the scope of the topic forbidding. Inroads are exemplifed by the works of Thorndike (18,19,20), Dewey (6), and Pratt (14). Thorndike's concern was the frequency of usage of the word in printed language of "common knowledge". Other tabulations of words are available, most of them word counts of the language of special groups, particularly of age levels (1,4,5,7,8,9). This approach to language, aside from an applied connotation, focuses upon the probability of a word.

Dewey added phonetic tabulations, or "sound counts," and syllable tabulations to an enumeration of the frequency of common words. His work formed the basis for the development of a system of shorthand. As Morse code devotes minimum space to the frequent letter e, so efficient transcribing of acoustic language by shorthand is facilitated when simple characters represent the most frequent units of speech. Voelker (21,22,23,24,25) added relevant studies that were less extensive than Dewey's. These investigations permit statements of the probability of speech sounds.

Pratt, in the context of cryptography, emphasized the aspect of probability with respect to letters in printed English. In addition to the frequency of single letters and their occurrence in initial and terminal positions in words, he determined the relative frequency of digrams and trigrams and enumerated the more frequent trigrams.[1]

[1] Pratt used bigram to denote a pair of letters. Digram is in current use. Digram may seem to have appropriateness for written language, not spoken language. However, the word has been accepted by electrical engineers in reference to pulses, etc. Since the meaning of digram has already been "extended", since diphthong is not available for the present meaning and a new word such as biphthong would be cumbersome, digram is used here to mean two sounds.

Among other approaches to the statistics of language, Newman (13) applied autocorrelation techniques to the vowel-consonant sequences and Lotz (11) and Menzerath (12) developed graphical representations of "frequency of occurrence". Information theory (17,26) provides another technique for quantifying language. This methodology includes (a) a unit of measurement, the bit, (b) a point of view that is intuitively valuable, "the reduction of uncertainty", and (c) a mathematical treatment. The receiver or listener is viewed as being in a state of uncertainty about which symbol of a prescribed set he is to receive. If the symbols (sounds, letters, words, etc.) contribute equally to reducing this uncertainty, the symbols will be operating at the limit of their possibilities insofar as information transmission is concerned. This high efficiency of information transmitted per symbol could obtain only with independence among the symbols, i.e., with no "intersymbol influence", and if the symbols did occur with equal probability there would be no intersymbol influence. A circumstance in which each symbol of the collection of symbols has an equal opportunity of occurring next does not obtain in any aspect of English: letters are not equally frequent, sounds are not equally probable, some words do not ordinarily follow other words, etc. Information theory assesses information per symbol as the amount by which uncertainty is reduced on the average on receiving the symbol. The quantitative difference between the maximum information per symbol and the actual information per symbol, divided by the maximum information per symbol, is called redundancy. With no redundancy in the language, each symbol would occur with equal probability; and as the intersymbol influence increases or the probability of one symbol approaches unity, the redundancy of the language approaches a maximum value of unity.

PROBLEM

The present study is a "finger exercise" in applying elementary techniques of information theory to phonetic probability. One- and two-syllable isolated words were sampled with respect to (a) the relative frequency of speech sounds, $p(i)$ (to be read "the probability of sound i"), (b) the relative frequency of occurrence of the sounds at different positions in the word, (c) the probability of two sounds occurring in succession, $p(i,j)$ (to be read "the joint probability of a sequence of sounds designated i and j"), (d) the probability that one sound follows another, $p_i(j)$ (read "the conditional probability that sound j follows sound i"), and (e) probability that a sound will precede another, $p_j(i)$ (read "the conditional probability that sound i precedes sound j").[2] Words of one and two syllables and of differing

[2] At first thought, it may appear that values d and e should be identical. An analogy will make the disparity clear. In ordinary spelling, $p_i(j)$ equals unity when the i-symbol is the letter q and the j-symbol is the letter u, for q is always followed by the letter u, as in quay, quiet, etc. However, as one "reverses his field" and starts backward from the letter u, he finds that many letters may precede it, as lute, rule, etc. Thus, $p_j(i) < 1$ when the letter u is the j-symbol.

numbers of sounds were treated separately. The principal objective was to estimate the information of sounds and digrams. This would lead to an estimate of the redundancy that might be ascribed to the phonetic structure of words. A secondary objective was enumerative, to find the probability of the sounds and digrams represented by the sample.

The narrowness of the problem is emphasized. The sample was not continuous language and it might be regarded as zero-order approximation to the language of speech, i.e., an array of words not weighted by their probability. In contrast, the studies cited above, e.g. 6, 11-14, 18-25, involved first-order approximations to language, words weighted by their frequency of occurrence. Thus, interpretation and application of the present results are limited to matters pertaining to single words, for example, words that are sometimes enumerated as oral drills, singularly loaded with a phoneme in three positions: initial, final, and "medial". Should the drill-maker wish to employ probable and improbable phonetic environments for the phoneme, based on an unweighted population of "root" words, the present material would be relevant.

PROCEDURE

The sample of words included 1549 of one syllable and 2151 of two syllables. They had been selected from words of Thorndike ratings 1-10 through excluding homonyms, homographs, and words of greatest and least intelligibility (included: > 20% < 80% when heard through headsets in high-level noise and recorded as write-down items). The sample was available with the phonetic spellings entered on IBM cards (2). The representativeness of the selected sample with reference to the Thorndike list was checked in some particulars. For example, the proportion of initial letters had not been altered beyond "chance". However, words of two sounds among one-syllable words and words of seven or more sounds among two-syllable words were disproportionately infrequent. The principal analyses were applied to five categories of words, designated by an asterisk in the following summary of the sample:

Sounds	1 Syllable	2 Syllable
3	91	---
3	679*	47
4	628*	528*
5	151	765*
6	---	555*
6	---	256

A major limitation of the sample would seem to lie in the fact that the words were only root forms, present tense, etc.; no plurals, etc.

Three students of speech transcribed the words phonetically; two had taught phonetics. All used General American pronunciation. The work of each transcriber was reviewed by the remaining two. The 49 sounds that were used are indicated in Table 1.* They included four syllabic sounds, [l̩], [r̩], [m̩], and [n̩]; these reduced the shwa's of the alternative transcriptions [əl], [ər], [əm] or [ən]. Subsequently, because of small numbers of entries in some cells the populations of some related sounds were pooled: all sounds of an r character, [r], [ɚ], [ɝ], [r̩]; [eɪ] and [e]; [oʊ] and [o]; [l] and [l̩], [m] and [m̩], and [n] and [n̩], reducing the categories to 41. The IBM cards were dichotomized by syllables, sub-sorted according to number of sounds, sorted within each category for the presence of each sound, and re-sorted for each sound adjacent to each other sound.

The procedures of information theory assume that a sample is representative of an infinite population. This assumption is rarely fulfilled in studies of language. For example, in a study of vocabulary involving nearly a third of a million words uttered by college students in classroom speeches, one-third of the 6000 different words were used only once (1).

In a sample of continuous speech each sound would be both an i-sound and a j-sound in successive digrams. However, the transcription of running speech would either include a space at the end of a word or reserve the space for arbitrarily defined pauses. The space might be treated as a symbol in which case each sound would be, as stated above, both i and j at different times.[3] This condition would obtain if the discreteness of each word were preserved. For example, in a three-sound word only the first two sounds can be i's and the last two j's and only one sound can be both i and j in treatments of the digrams. This might be called an end problem and it occurs with each word in the population. In the word top, [tɑ] and [ɑp] are (i,j) digrams but there is no opportunity for [t] to be j nor for [p] to be i if the word is treated singly. Thus, in determining the average information of digrams, the number of sounds from which the (i,j) digrams were derived in each category of words was number of phonemes in the words minus the number of words of the category. Shannon retained the identity of the word in his work, noting, "A word is a cohesive group of letters with strong internal statistical influences...."(15). A consequence of this treatment is the possibility that information values of i's and j's will differ if sounds occur with differing frequencies in initial and final positions.

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* The phonetic alphabet appears with illustrations in the Appendix.

3 During the writing of this paper the author has received from John B. Carroll (3) a progress report on a study of probabilities of English phonemes. He treats a sample of continuous language with a space or 27th letter occurring between successive words.

A model for arranging the raw scores for the computational procedures relative to each category of words follows:

Sound ($\underline{j}$) following sound ($\underline{i}$)

$$
\begin{array}{c|cccccccc}
 & 1 & 2 & 3 & \cdots & (j) & \cdots & 41 \\
\hline
1 & n_{11} & n_{12} & \cdots & \cdots & n_{1j} & \cdots & n_{1(41)} \\
2 & \vdots & & & & & & \\
3 & \vdots & & & & & & \\
\vdots & \vdots & & & & & & \\
\text{Sound } (\underline{i}) \quad (i) & n_{i1} & \cdots & \cdots & \cdots & n_{ij} & \cdots & n_{i(41)} \\
\vdots & \vdots & & & & \vdots & & \vdots \\
41 & n_{(41)1} & \cdots & \cdots & \cdots & n_{(41)j} & \cdots & n_{(41)(41)}
\end{array}
$$

Four probabilities were determined with respect to each category of words:

$$p_j(i) = \frac{n_{ij}}{\sum_i n_{ij}} \qquad (1)$$

$$p_i(j) = \frac{n_{ij}}{\sum_j n_{ij}} \qquad (2)$$

$$p(i,j) = p(i)p_i(j) \qquad (3)$$

$$p(i) = \frac{\sum_j n_{ij}}{\sum_i \sum_j n_{ij}} \qquad (4)$$

RESULTS AND DISCUSSION

Two objectives were stated above: (a) to estimate the information in the sound and digrams of words, and (b) to enumerate certain phonetic probabilities.

A method of estimating average information suggested by Shannon (15,16) may be applied progressively through (a) "a circumstance of no intersymbol influence", (b) a condition that represents the frequency of each symbol, (c)...of each digram, (d) trigram, etc. In his notation, F_0, F_1, and F_2 represent successive estimates of H, each succeeding one determined from a more complete account of the statistics of the language. Thus, in the present application, F_0, F_1, and F_2 appraise respectively (a) equal probability of all sounds, (b) observed probability of all sounds, and (c) observed probability of all sounds in digrams. The relevant formulas for determining the average information per symbol follow, with illustrative computations to indicate that with no intersymbol influence and with equally probable sounds, the solutions for b and c would yield the same value as a.

$$F_0 = \log_2 N \text{ or} \tag{5}$$

$$= -\log_2 \frac{1}{41} = 5.35 \text{ bits per sound}$$

$$F_1 = -\sum_i p(i) \log_2 p(i) \text{ or} \tag{6}$$

$$= 41(.1306) = 5.35 \text{ bits per sound}$$

$$F_2 = -\sum_{i,j} p(i,j) \log_2 p_i(j) \tag{7}$$

$$= -\sum_{i,j} p(i,j) \log_2 p(i,j) + \sum_i p(i) \log_2 p(i)$$

$$= 41^2(0.00637) - 41(0.1306)$$

$$= 10.70 - 5.35 = 5.35 \text{ bits per sound}$$

The foregoing computations illustrate the application of three of Shannon's formulas for the calculation of average information per symbol. The maximum average information per digram would be double the value per sound, 2(5.35) = 10.70 bits. However, to maintain a basis for easy comparison the present results are stated as average information per sound.

To the extent that the sounds of the present samples do not occur equally, the average information per symbol is attenuated from 5.35 bits. Formula 6 (above) was applied to both the i and j sounds of the digrams of the words of

each category.[4] First, the formula was applied as written, and then was altered through substituting j for i. The average information per sound in bits and the average redundancy follow:

H or F_1 (bits) and Redundancy (R)

	one-syllable words				two-syllable words			
	i-sounds		j-sounds		i-sounds		j-sounds	
	bits	R	bits	R	bits	R	bits	R
3-sound	5.04	.06	4.65	.13				
4-sound	4.15	.22	4.40	.17	4.68	.13	4.31	.19
5-sound					4.48	.16	4.15	.22
6-sound					4.40	.18	4.33	.19

Shannon explains that the information of a digram is either equal to or less than the sum of the information of each of the symbols of the digram. Equality can obtain only in the event of no intersymbol influence as in the illustrative computation in formulas 6 and 7 (above). Thus, the average information per symbol in the digrams of 3-sound words would be expected to be less than $\frac{5.04 + 4.65}{2}$, or 4.85 bits. Computations of the information of the digrams yielded the following average information per symbol and the indicated values of redundancy:

F_2 as an estimate of H (bits) and redundancy (R)

	one-syllable words		two-syllable words	
	bits	R	bits	R
3-sound	4.21	.21	----	
4-sound	3.35	.37	3.89	.27
5-sound	----		3.89	.27
6-sound	----		3.75	.30

[4] An earlier discussion explained that the numbers of each sound treated as "digram-sounds" were attenuated because of the end problem. However, for the sake of comparison, all of the sounds of all categories of words were pooled and the average information per sound determined. This yielded 4.46 bits per sound.

First, the trend is obvious, both in the calculations of the average information per sound of the digrams and of the digrams themselves, that the symbols of the "shorter" words convey more information than do those of the "longer" words.

Second, in four of the five instances the average information per sound was greater when computed on the basis of going from "sound $\underline{i}$ to the following sound $\underline{j}$" than *vice versa*. In the "on-going" circumstance the final sounds of the words were by definition $\underline{j}$'s and never $\underline{i}$'s; in the "backward looking" instance the initial sounds were only $\underline{i}$'s and never $\underline{j}$'s. Thus, one might conclude that the initial sounds contain more information than the final sounds of words and also that a "preceding" sound conveys more information on the average than a "following" sound. This backward look at a supposedly on-going phenomenon is somewhat irregular. It is remindful of the changes that are introduced in the identification of the phonetic character of a preceding sound in synthesized speech by the modification of a subsequent sound (10).

Third, the phonetic structure of language is such that some sounds tend to be adjacent more frequently than others. Hence, the average information per sound in digrams is less than the average information per sound when the sound is treated as an isolated unit (although in a position to be either member of a digram). The decrements in information from (a) maximum or F_0, to (b) observed average bits per symbol $\frac{(i \neq j)}{2}$ or F_1, to (c) observed bits per "digram symbol" or F_2 are in the various instances:[5]

	(a)	(b)	(c)
3-sound, 1 syllable	5.35	4.85	4.21
4-sound, 1 syllable	5.35	4.28	3.35
4-sound, 2 syllable	5.35	4.50	3.89
5-sound, 2 syllable	5.35	4.32	3.89
6-sound, 2 syllable	5.35	4.37	3.75

[5] There is general interest in the amount of loss in efficiency of a language through redundancy. The present values relate to an assumption of maximum utilization of a system of 41 symbols. The second and third values of Row one could be achieved with 29 and 19 symbols; Row two: 20 and 10 symbols; Row three: 23 and 15 symbols; Row four: 20 and 15 symbols; and Row five: 21 and 14 symbols. This circumstance would, of course, presume equi-probable use of the symbols. The listener would have no clue within the word about what sound was coming next and the vocabulary would include all permutations of, for example, [dɑl] including [ɑld] [lɑd] [ldɑ] [dlɑ] [dɑl] [ɑdl]. Obviously, as redundancy is reduced, the requirement for accuracy in symbol-by-symbol reception grows larger.

On the basis of the above numerical values, the present phonetic code is being employed with relative efficiency in monosyllables of three sounds. Possibly the generalization is warranted that the efficiency with which the phonetic structure of English operates decreases within words of a particular syllabic length as the number of sounds increases.

The second set of results of this study applies a "frequency-of-occurrence" tabulation of sounds to the "mono-frequency" sample of words. For example, Table 1 summarizes an enumeration of the relative frequency of the 41 sounds in the population of words with initial, "medial", and final sounds treated separately. The table indicates the probability of each of the sounds among a population of initial sounds, a population of "medial" sounds, and of final sounds in a non-repeating, dictionary-like group of one- and two-syllable words. In this instance there is no "end problem" and all of the phonemes of the words are represented.

One method of tabulation might show the proportions with which each phoneme succeeds each other phoneme, these being so arranged that the rows, for example, would represent the _i_-sounds, and the columns, the _j_-sounds. Frequency or proportion of joint occurrence would be indicated and this "cell" value would state the probability that the sound _j_ follows the sound _i_ in one- and two-syllable words of various numbers of sounds. The same tables could be read vertically through the columns to find $p_j(i)$, or the probability that an _i_-sound precedes an observed _j_-sound. Such tables, though available, tend to become excessive in size. Accordingly, the more frequent combinations have been extracted and appear in Tables 2 and 3. These two tables are not to be interpreted as listing the most frequent pairs of sounds in the words. This emmeration appears in Table 4. The entries in Table 2 relate to transitional probability: if _i_-sound occurs, then the chances are at least one in 10 that _j_-sound will occur. The i-sounds stand before the colon. Table 3 is similar to Table 2 except that the transitional probabilities are based on $p_j(i)$. However, the _i_-sounds again are before the colon as in Table 2.

Table 4, as described above, lists the most frequent digrams in terms of joint probability. The table enumerates the digrams that have at least a probability of .003 each.

A feature of digram probability that is revealed by treating words of various lengths separately is that different transitional probabilities occur with the same digrams in the different categories of words. The nine isolated examples that follow are selected from the 41 x 41 matrix to illustrate this point. In these nine examples, the _j_-sounds appear over each example and the _i_-sounds at the left side.

		Example 1 [s] 1-syllable	2-syllable		Example 2 [ɪ] 1-syllable	2-syllable		Example 3 [ɪ] 1-syllable	2-syllable
3-sound		0.7			3.7			2.2	
4-sound	[l]	4.9	1.9		9.3	4.5		39.4	0.6
5-sound			11.6	[l]		17.5	[s]		2.1
6-sound			17.8			15.8			6.1

		Example 4 [k] 1-syllable	2-syllable		Example 5 [n] 1-syllable	2-syllable		Example 6 [æ] 1-syllable	2-syllable
3-sound		-			6.6			5.2	
4-sound		13.5	0.6		6.6	8.9		11.5	1.9
5-sound	[s]		2.1	[ɪ]		14.7	[l]		2.1
6-sound			6.1			17.8			4.8

		Example 7 [ɪ] 1-syllable	2-syllable		Example 8 [ɪ] 1-syllable	2-syllable		Example 9 [ɪ] 1-syllable	2-syllable
3-sound		3.7			5.2			2.2	
4-sound		-	12.1		7.1	18.1		2.7	8.0
5-sound	[d]		13.0	[r]		22.3	[t]		10.3
6-sound			12.9			21.7			8.3

The five values of <u>Example 1</u>, for instance, indicate that in three-sound words, the particular <u>j</u>-sound followed the particular <u>i</u>-sound with only one-seventh the probability that the same <u>j</u>-sound followed the same <u>i</u>-sound in four-sound, one-syllable words. This variability is even greater in two-syllable words. If the two-syllable word of this example contains six sounds, the probability is nine times as great as if the word has only four sounds that when <u>i</u> occurs, <u>j</u> will follow.

EXEMPLIFICATION AND SUMMARY

From a non-repeating population of root words a listener might hear a sample of five words, one of each of the five lengths that have been treated here. There is a biased probability with respect to the acoustic events in each word. The words might begin with the five most frequent initial sounds: [s], [k], [p], [b], and [r]. The most probable sets of acoustic events in the five words, together with their probabilities are: [sut], ---, 0.152, 0.156;[6] [kren], ---, 0.256, 0.103, 0.280; [plebr], ---, 0.197, 0.292, 0.157, 0.157 (on the basis of one-syllable probabilities); [bɪtɪ], ---, 0.240, 0.138, 0.195 (on the basis of two-syllable probabilities); [rɪsɪtrɪ], ---, 0.219,

---

6 By way of further explanation, in three-sound words, [s] having occurred, [u] has a probability of 0.152 of occurring as the next sound; and [u] having occurred, [t] is the most probable succeeding sound with a probability of 0.156.

0.173, 0.335, 0.345, 0.219. Similar procedures originating with the five most frequent terminal sounds yield the following results (read the probabilities from right to left): kæt , 0.113, 0.118, ---;[7] [ɑrɛn], 0.118, 0.188, 0.135, ---; [tætæt], 0.125, 0.146, 0.125, 0.146, ---; [rɪmb], 0.169, 0.178, 0.227, ---; [rɪstrɪ], 0.220, 0.273, 0.242, 0.185, 0.220, ---. The examples indicate that in a sequence of English phonemes there are transitional probabilities of an order to indicate at least one chance in 10 that a particular sound will be next and that these chances may exceed one in three in some sequences.

In summary, the phonetic elements of English in root forms of words have dissimilar frequencies in the language, both in isolation and as digrams. These frequencies are not independent of the preceding and succeeding sounds. When the adjacent sounds are treated as pairs, the average redundancy is at least .20, and within the categories of words sampled reached .37. The sounds of words of three phonemes contain more average information per sound than do the sounds of longer words.

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[7] In this instance, [t] is the selected final sound. In three-sound words the most likely sound to precede [t] is [æ] and the probability is 0.118; in turn, the sound most likely to precede [æ] is [k], 0.113.

REFERENCES

1. Ausherman, M., and J. W. Black. Formal spoken vocabulary of college students. Pensacola: Joint Project, Ohio State Univ. Res. Found. and U. S. Nav. School of Av. Med., 1950. Joint Project Report no. 3. The Bureau of Medicine and Surgery Project NM 001 064.01.03.

2. Black, J. W. Accompaniments of word intelligibility. J. of Speech and Hearing Disorders, 1952, 17, 4, 409-418.

3. Carroll, J. B. Personal communication.

4. Dale, E. Bibliography of Vocabulary Studies. Columbus, Ohio: Bureau of Educational Research, The Ohio State Univ., 1949.

5. Dale, E., and J. S. Chall. A Formula for Predicting Readability. Columbus, Ohio: Bureau of Educational Research, The Ohio State Univ., 1948.

6. Dewey, G. Relative Frequency of English Speech Sounds. Cambridge: Harvard Univ. Press, 1923.

7. Fossum, E. An analysis of the dynamic vocabulary of junior college students. Speech Monogr., 1944, 11, 88-96.

8. Gates, A. I. A Reading Vocabulary for the Primary Grades. New York: Bur. of Publications, Teachers Coll., Columbia Univ., 1935.

9. Horn, E. H. Basic Writing Vocabulary: 10,000 Words Most Commonly Used in Writing. Iowa City: Univ. of Iowa, 1926.

10. Liberman, A. M., P. Delattre, and F. S. Cooper. The role of selected stimulus variables in the perception of the unvoiced stopped consonants. Amer. J. of Psychology, 1952, 65, 497-516.

11. Lotz, J. Speech and language. J. of Exp. Psychology, 1952, 44, 712-717.

12. Menzerath, P. Typology of languages. J. acoustic. Soc. Amer., 1950, 22, 698-701.

13. Newman, E. B., and L. J. Gerstmore. A new method for analyzing printed English. J. of Exp. Psychology, 1952, 44, 114-125.

14. Pratt, F. Secret and Urgent. Indianapolis: Bobbs Merrill, 1939.

15. Shannon, C. E. Prediction and entropy of printed English. Bell Syst. Tech. J., 1951, 30, 1, 50-64.

16. ______________ The redundancy of English. Cybernetics, Transactions of Seventh Conf. (1950), Josiah Macy Jr. Found., 1951, 123-158.

17. Shannon, C. E., and W. Weaver. The Mathematical Theory of Communication. Urbana: Univ. of Illinois Press, 1949.

18. Thorndike, E. L. A Teacher's Word Book of the Twenty Thousand Words. New York: Bur. of Publications, Teachers Coll., Columbia Univ., 1932.

19. ______________ Century Junior Dictionary. New York: D. Appleton-Century Co., 1942.

20. Thorndike, E. L., and I. Lorge. The Teacher's Word Book of 30,000 Words. New York: Bur. of Publications, Teachers Coll., Columbia Univ., 1944.

21. Voelker, C. H. A new sound count for logopedists. Annals of Otology, Rhinology and Laryngology, 1935, 44, 1, 260.

22. ______________ An objective study of the comparative number of speech sounds spoken per minute by the deaf and the normal. Annals of Otology, Rhinology and Laryngology, 1937, 46, 2, 471.

23. ______________ A comparative study of investigations of phonetic dispersion in connected American English. Arch. Neerlandaises de Phonetique Experimentale, 1937, 13.

24. ______________ The influence of spoken and written material on the phonetic predominance. Arch. Neerlandaises de Phonetique Experimentale, 1939, 15.

25. ______________ One-thousand most frequent spoken words. Quarterly J. Speech, 1942, 28, 189-197.

26. Weaver, W., G. E. Peterson, and H. Davis. Information theory. J. Speech and Hearing Disorders, 1952, 17, 166-197.

Table 1. The proportions of initial, "medial", and final positions of words of different lengths that contain the indicated sound. The proportions appear separately for 1- and 2-syllable words. Read as chances in 100.

	initial		medial		final	
	1-syllable	2-syllable	1-syllable	2-syllable	1-syllable	2-syllable
i	0.20	0.37	4.10	2.12	0.60	0.09
I	0.50	4.80	7.50	10.71		9.16
e-eI	0.30	0.37	4.60	2.53	1.30	1.92
ɛ	0.50	1.02	5.80	3.93		
æ	0.50	1.07	7.20	3.97	0.10	
ɑ	0.50	0.84	4.50	2.79	0.10	0.09
ɔ	0.10	0.79	3.90	1.78	0.50	0.05
o-oʊ	0.40	0.88	4.10	2.08	0.80	1.59
ə		3.96		5.17		0.51
ʌ	0.10	0.37	5.50	2.25		
ɚɝr̩	4.70	6.56	15.30	10.06	3.60	16.87
u	0.10		3.20	1.46	0.80	0.42
ʊ			0.30	0.17		
ɔI	0.10	0.14	0.50	0.20	0.30	
aʊ	0.10	0.51	1.90	0.61	0.30	0.05
aI	0.10	0.28	3.90	2.28	1.20	0.56
ju	0.10	0.14	0.30	0.46	0.10	0.23
p	6.80	8.10	2.40	2.69	5.80	0.79
b	8.60	6.98		1.78	2.00	0.61
t	6.60	4.75	2.60	5.75	17.20	14.49
d	5.00	6.05	0.20	2.86	3.80	6.82
k	9.10	8.52	2.10	3.83	8.70	2.48
g	6.20	2.93	0.10	1.17	2.20	0.19
f	7.00	5.87	0.20	1.75	2.60	0.70
v	1.40	1.77	0.20	1.44	2.70	1.03
θ	1.80	0.79		0.32	2.60	0.56
ð	0.50	0.33		0.32	0.30	0.05
s	16.90	10.57	2.80	4.46	6.20	8.27
z	0.10	0.19	0.10	0.94	3.50	2.06
ʃ	3.00	0.74		0.79	1.90	1.17
ʒ		0.05		0.09		
h	4.70	4.05		0.27		
tʃ	1.70	0.88		0.43	3.90	0.33
dʒ	1.30	0.88		0.64	2.60	1.96
m-m̩	3.60	5.35	1.30	3.06	4.80	2.34
n-n̩	2.40	1.77	5.10	7.12	6.50	10.93
l-l̩	4.90	3.91	7.20	5.86	6.20	11.59
w	3.80	2.89	1.90	0.92		
hw	0.80	0.42		0.07		
j	0.60		2.00	0.23		
ŋ			1.20	0.66	1.90	2.01

Table 2. An emmeration of instances, based on an alphabet of 41 sounds, in which $p_i(j)$ exceeds one in 10; an asterisk indicates that $p_i(j)$ exceeds one in five; and an underlined entry, that it exceeds one in four. The i-sounds precede the colon. The following sounds are pooled: [o,ov], [e,eɪ], [r,r,ɚ,ɝ], [m,m̩], [n,n̩], and [l,l̩].

A. Three-sound, one-syllable words. N digrams, 1358.

i:	p,t,d,l.
ɪ:	t,n.
e:	v,k,t,m.
ɛ:	t,r,n,l.
æ:	k,t, .
ɑ:	t,r,k b,p.
ɔ:	t,s,l,k.
o:	z,l,k.
ʌ:	g,m,ŋ.
u:	t,k,m.
ʊ:	l*,t*,ʃ*.
aʊ:	t*,n,tʃ,θ.
aɪ:	n,r,t,d,l.
p:	ɪ,æ,r.
b:	ʌ,æ.
t:	r,ʌ,aɪ.
d:	ɪ,ɛ,ɑ,ʌ,r.
k:	æ,o,ʌ.
g:	æ,ɪ,o.
f:	ɑ,aɪ,r.
v:	r*,æ,aɪ.
θ:	r.
ð:	ɛ,i,æ,o,
s:	u,ɪ,i.
z:	i,ɑ.
ʃ:	i,e,ɑ,u.
h:	ʌ,ɪ,æ,ɛ,u.
tʃ:	ɪ,æ,i,e,ɔ.
dʒ:	ɪ,ɑ,ɛ,ʌ.
m:	æ,ɑ,u.
n:	i,e,æ,ɑ,o.
l:	i,æ.
w:	ɪ,ɛ,i,e,ɔ.
hw:	ɪ*,aɪ*,i,ɑ.
j:	ɑ*,ɔ,ʌ,r.
ŋ:	k.

B. Four-sound, one-syllable words. N digrams, 1884.

i:	d,k,s,m.
ɪ:	n,s,ŋ,f,l.
e:	k,s,t,z,n*.
ɛ:	n,s,l,z,d.
æ:	s,n,k,ŋ,m.
ɑ:	r*,k.
ɔ:	r*,l,n.
o:	r*,l*,s.
ʌ:	n,m,l.
r:	e.
u:	t,l,p,d,m,n.
ʊ:	k*,r*.
ɔɪ:	l*,s*,n*.
aʊ:	n*,t,d.
aɪ:	n,t,d.
p:	r,l.
b:	l.
t:	r*,e.
d:	r*,ʌ.
k:	r*,l,w.
g:	r*,l.
f:	r,l,t.
v:	ɛ*,æ*,ɔ*,l.
θ:	l*,r*.
s:	t*,p,k.
ʃ:	r*,æ,ɛ,ɑ.
h:	ɑ*,ɪ,ɛ.
tʃ:	æ*,ɑ*,ɪ,e,ɔ,ʌ.
dʒ:	ɛ*,o*,ʌ*.
m:	p*,ɪ,aɪ.
n:	tʃ*,t,d,s.
l:	æ,t.
w:	r*,ɛ.
hw:	ɪ*,ɛ*,ɔ*.
j:	u*,i,ɛ,ɑ.
ŋ:	k*.

C. Four-sound, two-syllable words. N digrams, 1584.

i:	d,p,t.
ɪ:	n,t.
e:	b,s,p,l.
ɛ:	r,l,n,t.
æ:	t,l.
ɑ:	l,r,t.
ɔ:	r,t,l,s.
o:	k.
ə:	l*,b,m.
ʌ:	t,d,n.
r:	*.
u:	d,l.
ʊ:	r*,l*.
ɔɪ:	s,z,n,l,ə,t.
aʊ:	t*,r.
aɪ:	t,d,r,n.
ju:	r*,t*.
p:	l,r,ɪ.
b:	l,r,ɪ.
t:	r*,ɪ,l,n.
d:	l*,r,n,l.
k:	r,l.
g:	r*,ɪ,n.
f:	r*,ɑ,e,aɪ.
v:	i,ɪ*.
θ:	ɪ*,e,ə.
ð:	r*.
s:	ʌ,i,l.
z:	l*,r*,n.
ʃ:	ʌ,ɪ,æ,o.
ʒ:	r.
h:	æ,ɛ,ɑ,ʌ.
tʃ:	r*,æ*,ɪ,aɪ.
dʒ:	r,u.
m:	ɪ*,e,ʌ,r,æ.
n:	ɪ*,r.
l:	e,r,o.
w:	d,e,ɪ.
hw:	aɪ*.
j:	r*.
ŋ:	r*,ɪ*,k*.

D. Five-sound, two-syllable words. N digrams, 1060.

i:	t,m,n.
ɪ:	t,n,s.
e:	n,t,s,d,m.
ɛ:	ɪ,n,s,k,l.
æ:	n,m,k.
ɑ:	r*,l.
ɔ:	s,l,r*.
o:	l,r,t,k,n.
ə:	n*,l,s.
ʌ:	n*,m,s,b.
u:	t,l,n,r.
ʊ:	ʃ*,l*,r*.
ɔɪ:	n*,ə,s,l.
aʊ:	n*,t*.
aɪ:	n,t,d.
ju:	s,k,m,t,z.
p:	r,æ,ɑ,l.
b:	l,ɪ,r.
t:	r*,ɪ,l.
d:	r,ɪ*.
k:	r,ɪ,ə,l.
g:	l*,r,ɪ,ɑ.
f:	l,ɪ,r,ɔ.
v:	ɪ*,r.
θ:	ɪ*,ɔ,ə.
ð:	ɛ*,r*,ɪ,ə.
s:	t,ɪ.
z:	n,r,l,ɪ,ɛ.
ʃ:	ə*,r,m.
ʒ:	ɛ*,ə*,r*.
h:	æ,ʌ,ɑ.
tʃ:	r*,ɪ,ɛ.
dʒ:	r*,ə*,r,ɛ.
m:	ɪ,p.
n:	ɪ,t,d.
l:	ɪ*.
w:	ɪ*,r,ɛ.
hw:	ɛ*,ɪ*.
j:	r*,ə*,u*.
r:	ɪ.
ŋ:	ɪ*,ɛ*.

E. Six-sound, two-syllable words. N digrams, 2775.

i:	d,s,t.
ɪ:	s,n,t,k.
e:	n,k,t,d.
ɛ:	n*,s,l.
æ:	n*,k,s,m.
ɑ:	r*,k,l.
ɔ:	r*,l.
o:	r*,ɪ.
ʊ:	l*,t,k,r.
ə:	n*,l,s,m.
ʌ:	m,s,n,l.
u:	d*.
ɔɪ:	l*,s*.
aʊ:	n*,s,d,θ,z,r.
aɪ:	t,d,n,l,r.
ju:	b,t,d,v,m,w,s.
p:	r,l.
b:	l,ɪ,r.
t:	r*,ɪ.
d:	ɪ*,l.
k:	r,ə.
f:	ə,r,ɔ,ɪ.
v:	ɪ,r,e,ɛ,ɑ,ə.
θ:	ɪ,ɔ,r,f,l,w.
ð:	ɪ,ɛ,aɪ,d,s,r.
s:	t*,k.
z:	ɪ*,ɔ,ə.
ʃ:	ə*,r.
ʒ:	ɪ*,æ*,ə*.
h:	ɛ,æ,aɪ,ɑ,o.
tʃ:	ɪ,ə,aɪ,r.
dʒ:	ɪ,ɛ,i,ʌ.
m:	ɪ,ə,ɔ.
n:	t*,d,s.
l:	ɪ*,ə.
w:	r,ɪ,ɔ.
hw:	ɛ*,i,ɑ,aɪ.
j:	u*,ə*,r.
ŋ:	k*,g*,d,z,l.
r:	ɪ.

Table 3. An enumeration of instances, based on an alphabet of 41 sounds, in which $p_j(i)$ exceeds one in 10; an asterisk indicates that $p_j(i)$ exceeds one in five; and an underlined entry, that it exceeds one in four. The i-sounds precede the colon.*

A. Three-sound, one-syllable words. N digrams, 1358.

i: f,i,θ,z,tʃ,d,v.
e: ð*,v*,dʒ,k,z,m.
ɔ: s,[illegible].
r: dʒ,u,e,tʃ,o,b,θ,ʌ, aɪ,i,ɪ,æ.
ʊ: θ.
aʊ: tʃ.
b: ʊ*,ɔɪ,ʌ.
d: ɛ,aʊ,ɑ.
g: aʊ.
m: ju*.
l: i,[illegible],ɔɪ,æ,u,aɪ.
ɪ: ŋ*,ð*,g,p,d,tʃ,n,b, t,[illegible].
ɛ: dʒ,n.
æ: p,[illegible],k,g,f,ʌ,s,tʃ*, dʒ,ŋ.
ɑ: b*,p,k,g,dʒ,r,t.
o: z,v,l,p.
ʌ: ŋ*,g*,b,m,v,ʃ,f.
u: ʒ*,θ,m,k,f,s.
ɔɪ: n.
aɪ: v,ɑ,f.
p: ʊ*,ju,aʊ,ɪ,æ.
t: ɔ,ɔɪ,ju,r,aɪ.
k: ɔɪ*,æ,o,ʌ.
f: ɔɪ*,ju*,e,aɪ.
s: w*,j,a.
h: aʊ,ʌ.
n: ju.
w: ɛ.

B. Four-sound, one-syllable words. N digrams, 1994.

i: ð*,tʃ,m.
ɪ: ŋ*,f*,g,n,b,s,tʃ,a.
e: z*,n,v.
ɛ: ʃ,s,n,dʒ,d.
æ: g*,ʃ*,ŋ*,m,f,s.
ɑ: r.
ɔ: θ,f.
ɒ: b,z.
ʌ: g*,b*,m,ŋ,f,dʒ,tʃ.
r: θ*,ʊ*,aɪ*,e*,u*,au*, i*,dʒ*,ʌ*,ɔ*,ɔɪ*,ɛ, o,æ,ʃ,ɪ,v,d,tʃ,a.
aʊ: n.
aɪ: v,b,z.
p: ɔɪ*,aʊ,aɪ.
b: r,ɑ,v.
t: e,o,r.
d: i.
k: ʃ*,w*,o,l.
g: r.
f: j,z,ɔ.
θ: ɪ.
s: p*,t*,w*,k*,m.
h: ɔɪ*,j,ɑ.
m: b,p.
n: tʃ*,dʒ*,d,θ,t,s.
l: ʊ*,æ*,i,ɪ,v,ɛ,ʌ,d, ɑ,e,ɔ,aʊ,θ,aɪ,b,f, ʊ.
w: i.
j: u.
ŋ: k.

C. Four-sound, two-syllable words. N digrams, 1584.

i: tʃ,g,[illegible],z,p,ʒ*.
ɪ: ð*,f*,dʒ*,v,tʃ,m, g,[illegible],k,n,t,d,z,[illegible].
e: dʒ*,b,s,ʃ,p,z,v,k.
ɛ: ð*,f,dʒ,v.
æ: tʃ,ŋ,ɔ,t,k,b,m,d.
ɑ: ð,p,b.
ɔ: ʃ,j*.
o: k.
ə: b,p.
ʌ: z,d,f,k,ŋ.
r: tʃ*,ɔɪ,i,u,ɪ,o,aɪ, dʒ,g,n,l,θ*.
u: z.
aʊ: w*.
aɪ: ə,d.
p: ʌ,ɔ.
b: ʊ*,[illegible],ɔɪ,ɛ,ʌ.
t: w,aɪ,æ,r,ə,u,ʊ.
d: ɪ,n.
k: ɔ*,[illegible],ju,ɑ.
f: ju,ɑ,aɪ.
v: ə.
s: ʌ,ɛ,ɔ.
j: ʊ*.
h: æ,ɑ,ɛ.
dʒ: ɔɪ,[illegible].
m: ʌ,ɔ.
n: θ*.
l: ɔɪ*,e*,ʊ*,o,aɪ,i,ɛ, u.
w: d,ɔ.

D. Five-sound, two-syllable words. N digrams, 3060.

i: tʃ.
ɪ: ŋ*,h*,ʃ*,dʒ*,v*,f*, z*,k*,s*,ð*,t,d,m, θ,n,p,g,tʃ,w.
ɛ: ʒ*,k.
æ: ð*,ŋ,θ,v,g,m,k.
o: hw*.
ə: n,b,p,m,s.
ʌ: ð*,b,m.
ju: ʒ*.
p: ɑ,æ,o,ju,tʃ,ɔɪ.
b: ɔɪ,aʊ,h,ʌ,ɑ,ʊ*.
t: æ,r,e,[illegible],v.
d: ʒ*,j*,ju,i,ɪ.
ɔ: f.
k: ʌ,aʊ,ɑ,ə,v*,ɔ.
g: ɑ.
f: ju*,ɔ,aʊ.
v: aʊ,aɪ.
s: ʌ,w,tʃ,t,p,i.
h: ju.
m: b,ɔɪ,h,ŋ,o,æ,ɑ,ə,p.
n: ə,ʃ*,d*,h*,ɔɪ,θ,aʊ, ju,t,dʒ,j*.
l: u,aɪ,θ,[illegible],ə,ɪ,o,ə.
r: ʊ*,ð*,tʃ,u,b,e,i,æ, ɪ,ɛ,g,dʒ,d,t.
ŋ: g*.

E. Six-sound, two-syllable words. N digrams, 2775.

i: ð.
ɪ: ŋ*,dʒ*,g*,hw*,z*, k*,s*,ʃ*,v*,n,ð, h,θ,f,t,m,d.
e: θ,ʃ,v.
ɛ: p*,n,dʒ.
æ: b,dʒ.
ɑ: b.
ɔ: θ,r.
o: ð,z.
ə: n*,m,l,s.
ʌ: ŋ,m.
l: ɔɪ*,j*,æ,v,ɪ,o,ʌ, ə,f,aɪ.
w: ɔ,dʒ.
r: ʒ*,ð*,j*,i*,e,ɑ,ɪ, æ,ɛ,ʌ,aɪ,o,ə,aʊ,b, t,d,θ,ʃ*,w.
p: ʊ*,o*,ə,ɑ,ɛ.
b: ʊ*,ju.
t: ju*,r,aɪ,e,w,ɛ.
d: h,ju,ɪ.
k: hw*,w*,aʊ*,ə,j,æ,r.
g: ʒ*,u.
f: ɔ,u.
θ: aʊ.
s: t,p,i,tʃ,k,ʌ,aʊ,[illegible].
z: aʊ.
dʒ: h.
m: hw*,p*,b,j,[illegible],æ.
n: ɔɪ*,h*,ʃ*,d*,t,f, ju,tʃ,s,v,dʒ.
h: aʊ.

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*This table is not a true counterpart of Table 2. The differences between the two tables can be clarified through reference to the computational model. Table 1 was based on the probabilities of progressing from an i-sound to a j-sound. These probabilities would be taken from the rows of the computational model, each row totaling unity. Obviously, then, a maximum of 10 of the 41 cells in a row could have the probability "one in 10". A comparable procedure was followed in determining $p_j(i)$, with the probabilities of each column totaling unity. If the j-sounds were enumerated ahead of the colon in Table 3, this table would be directly comparable to Table 2. The i-sounds, however, precede the colon in Table 3; hence, in the extreme instance, as many as 41 j-sounds (or column headings in the model) might follow the colon, each with a probability of one in 10. Actually, as many as 20 do appear together in one entry in Table 3B. Thus, in 4-sound, one-syllable words, when the probabilities are stated in terms of the i-sounds that may precede the j-sounds, [r] is a highly probable event in 20 instances.

Table 4. An enumeration of instances in which digram probabilities, $p(\underline{i},\underline{j})$, of one- and two-syllable words of all lengths pooled exceed .003. An asterisk indicates that the probability exceeds .010. The i-sounds of the digram precede the colon.

A. One-syllable words.
N digrams, 3973.

ɪ: r, n, ŋ, p, t, s.
e: n*, k, t.
ɛ: n, l.
æ: n, s, ŋ, k, m, p, t, ʃ.
ɑ: r*, t, k.
ɔ: l, r.
o: l, r.
ʌ: n, m, s, ŋ.
aʊ: n.
aɪ: t, d, m.
ŋ: k.
p: r, l, æ, ɪ, ɛ.
b: r, l, æ.
t: r*.
d: r.
k: l, w, æ, o.
g: l, r.
f: r, l, t.
θ: r.
s: t*, p*, k*, l, w.
m: p.
n: t, d, s, tʃ.
l: aɪ*, ɪ, i, ɛ, t, ʌ, d.
w: ɪ, ɛ, k.
r: e, æ, ɪ, i, ʌ, u, ɛ, o, t, ɔ, ɑ, d, m, aʊ, aɪ.

B. Two-syllable words.
N digrams, 9024.

i: s.
ɪ: t*, k*, d, v, l, dʒ, p, f, ʃ, s*, n, m.
ɛ: n, s, r, t, k, d, l.
æ: n, k, l.
ɑ: r, n.
ɔ: r.
o: r, l.
ə: n, l, m, s.
ʌ: n.
p: r, l, ɑ, æ.
b: l, r, ɪ.
t: r*, l, n.
d: ɪ*, r, l.
k: r, ə, l, t, ɪ, ɛ, ɑ.
g: r.
f: r, ə.
v: r.
s: t*, ɪ, k, p, l.
ʃ: ə.
m: ɪ, p, ə.
n: d, ɪ, t*.
l: ɪ*, ɛ, ə, e, r, æ.
w: ɪ.
r: ɪ*, t, æ, d, ɛ, ə, e, i, n, aɪ.

APPENDIX

PHONETIC ALPHABET[8]

8 copied from Van Riper, C. G. and D. E. Smith, An Introduction to General American Phonetics, New York: Harper & Brothers, 1954.

CONSONANTS

Phonetic Symbol	English	Phonetics	Phonetic Symbol	English	Phonetics
[b	beg, tub	[bɛg tʌb	[p	paper, damper	[pepɚ dæmpɚ
d	do, and	du ænd	r	run, far	rʌn fɑr
f	fan, scarf	fæn skarf	s	send, us	sɛnd ʌs
g	grow, bag	gro bæg	t	toe, ant	to ænt
dʒ	judge, enjoy	dʒʌdʒ ɛndʒɔɪ	ʃ	shed, ash	ʃɛd æʃ
h	ham, inhale	hæm ɪnhel	tʃ	cheap, each	tʃip itʃ
k	kick, uncle	kɪk ʌŋkl	θ	thin, tooth	θɪn tuθ
l	let, pal	lɛt pæl	ð	then, breathe	ðɛn brið
l̩	apple, turtle	æpl tɝtl̩	v	vow, have	vaʊ hæv
m	men, arm	mɛn ɑrm	w	wet, twin	wɛt twɪn
m̩	autumn, wisdom	ɔtm̩ wɪzdm̩	hw	when, white	hwɛn hwaɪt
n	nose, gain	noz gen	j	you, yet	ju jɛt
n̩	sudden, curtain	sʌdn̩ kɝtn̩	ʒ	pleasure, vision	plɛʒʊr vɪʒən
ŋ]	wrong, anger	rɔŋ æŋgɚ]	z]	zoo, ooze	zu uz

VOWELS

Phonetic Symbol	English	Phonetics	Phonetic Symbol	English	Phonetics
[a	ask, rather	[ask raðɚ	[ɔ	sauce, off	[sɔs ɔf
ɑ	father, odd	fɑðɚ ɑd	ɝ	earn, fur	ɝn fɝ
e	make, eight	mek et	ɚ	never, percale	nɛvɚ pɚkel
æ	sat, act	sæt ækt	u	truth, blue	truθ blu
i	fatigue, east	fətig ist	ʊ	put, nook	pʊt nʊk
ɛ	red, end	rɛd ɛnd	ʌ	under, love	ʌndɚ lʌv
ɪ	it, since	ɪt sɪns	ə]	about, second	əbaʊt sɛkənd]
o]	hope, old	hop old]			

DIPHTHONGS

Phonetic Symbol	English	Phonetics	Phonetic Symbol	English	Phonetics
[aɪ	sigh, aisle	saɪ aɪl	[ɔɪ]	coy, oil	[kɔɪ ɔɪl]
aʊ]	now, owl	naʊ aʊl			